Dynamics and Duality of a Stabilized Radion

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Fermilab Theory Seminar

31 July 2014

arXiv: 1408.xxxx

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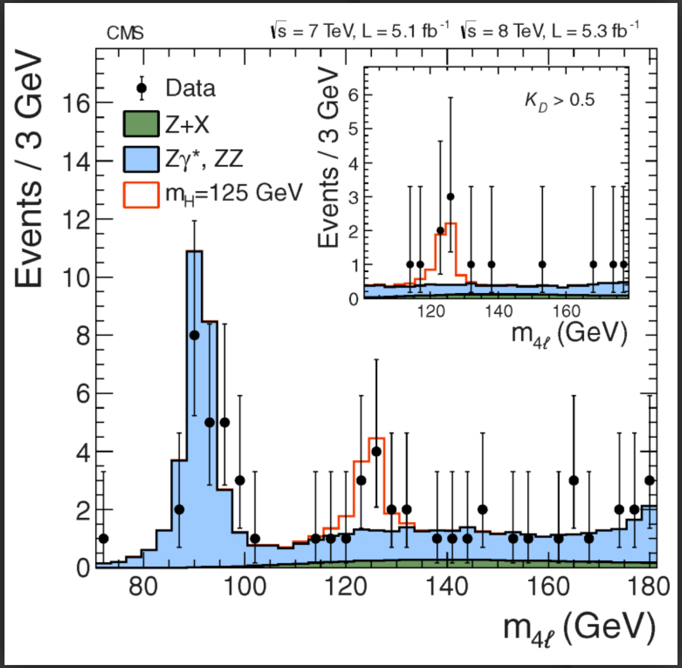
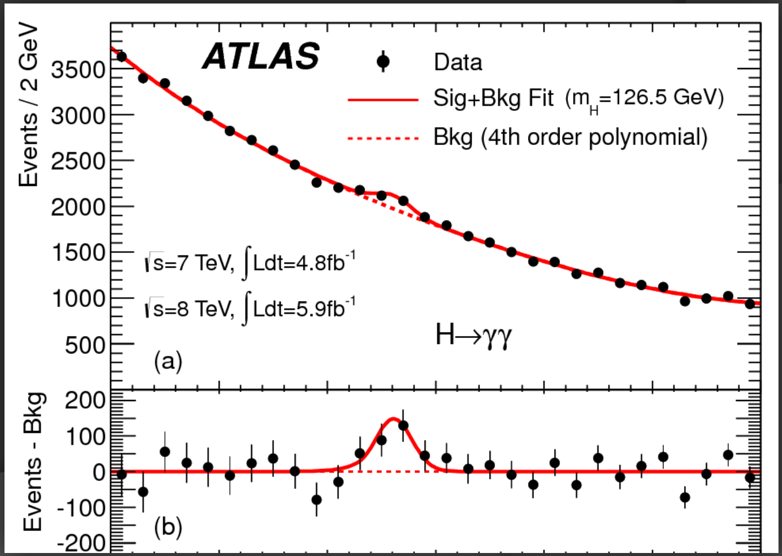
We have a Higgs!

- Next, understand EWSB
- Several possibilities address Planck-Weak hierarchy
- Two Roads: Elementary or Composite Higgs
- If composite, we must separate the weak scale from the flavor scale





Conformal Models

- Conformal dynamics can be used in composite Higgs models to separate EW and flavor scales
- RS models are dual to strongly coupled conformal dynamics through AdS/CFT
- RS models contain the Radion

Λ_{UV} Flavor/Planck Scale

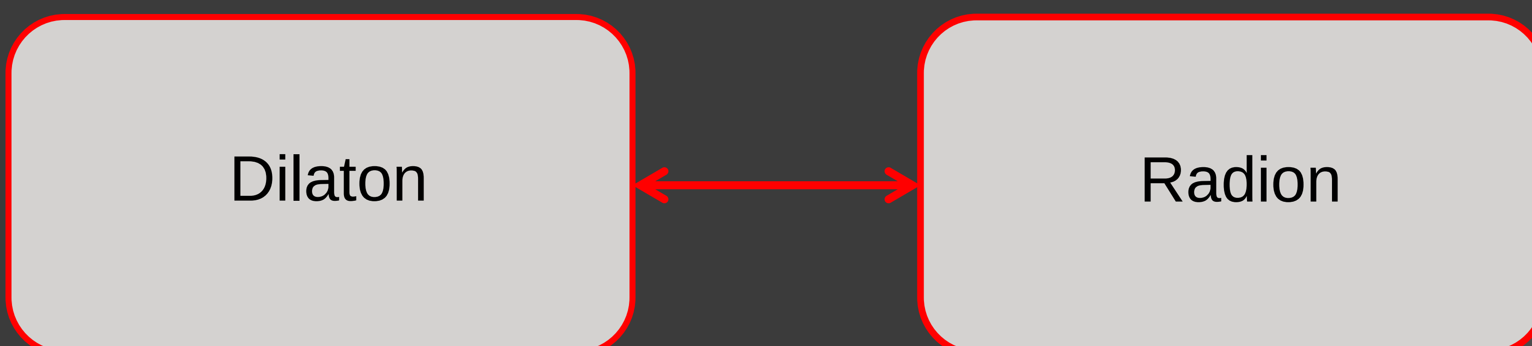
CFT

Λ_{IR} CFT Breaking Scale

EWSB

Outline

- Begin by recounting general known results about the dilaton of broken CFTs
- We then use these general results to understand the RS radion
- Great case study for AdS/CFT



The Dilaton σ

- The Standard Model is not conformal, so the symmetry must be broken, at scale f
- If the conformal symmetry was exact the low energy theory contains 1 massless NGB: the dilaton
  - Although 5 generators are broken only one NGB
- Couplings fixed to realize the broken symmetry nonlinearly
  - Tightly constrained

Explicitly Violated

- There is no such massless scalar field, so the conformal symmetry is explicitly broken
- The dilaton becomes massive
- Its couplings are corrected
- Two Questions
  - What is its mass?
  - How do its couplings change?

CFT $\leftrightarrow$ RS

- Answers are known in the CFT case
- The radion of Randall-Sundrum models with SM fields in the bulk is dual to the dilaton of a CFT with partially composite SM fields
- We will <u>calculate the couplings of a stabilized radion and show how they agree with the CFT analysis</u>

(Massless) Dilaton Properties

- Under $x \to e^{-\omega} x$ the dilaton shifts

$$\sigma \to \sigma + f\omega$$

  - Where f is the breaking scale
- It is convenient to define

$$\chi = f e^{\sigma/f}$$

- Which transforms as

$$\chi \to e^{\omega} \chi$$

Dilaton Couplings

- Consider gauge bosons that weakly gauge a global symmetry of the CFT (dual to gauge bosons in bulk of RS)
- Dominant coupling to σ comes from the non-scale invariant mass term
  - Choose the basis in which $$-\frac{1}{4g^2}F^2$$

$$d^4x\frac{m_W^2}{g^2}W_\mu W^\mu \to e^{-2\omega}d^4x\frac{m_W^2}{g^2}W_\mu W^\mu$$

Dilaton Couplings

- Need two powers of $\frac{\chi}{f}$ to compensate

$$\left(\frac{\chi}{f}\right)^2 \frac{m_W^2}{g^2} W_\mu W^\mu \Rightarrow 2\frac{\sigma}{f}\frac{m_W^2}{g^2} W_\mu W^\mu$$

- Looks Higgs-ish

Dilaton Potential

- The χ Lagrangian contains the usual derivative terms
- Because $d^4x \to e^{-4\omega} d^4x$ find unique potential

$$V(\chi) = \kappa_0 \chi^4$$

- Then κ_0 determines f
  - If $\kappa_0 > 0$ then $f = 0$. Symmetry never broken
  - If $\kappa_0 < 0$ then $f \to \infty$. Never conformal
  - If $\kappa_0 = 0$ then f is unconstrained. Tuned choice

Nearly Conformal

- Consider a deformed CFT with 1 relevant deformation

$$\mathcal{L}_{\rm CFT} + \lambda_{\mathcal{O}} \mathcal{O}$$

- Grows in the IR until symmetry is broken
- Gives a mass to the dilaton, changes couplings
- To get the required <u>big</u> hierarchy between EW and flavor scales, we need $\Delta_{\mathcal{O}} = 4 - \epsilon$

2 Conformal Limits

- If $\lambda_{\mathcal{O}} \to 0$ then we have an exact CFT
- This is the standard story
- However, if $\Delta_{\mathcal{O}} \to 4$ we also recover an exact CFT
- With $\Delta_{\mathcal{O}} = 4 - \epsilon$ we still have a small parameter even if $\lambda_{\mathcal{O}}$ is large
- Can use both limits to understand dilaton mass and couplings

A Light Dilaton

- Most interested in dilatons we can discover
- The mass of the dilaton can be lighter than the CFT breaking scale if explicit breaking is small
  - The deformation is small at the breaking scale

$$\hat{\lambda}_{\mathcal{O}} \equiv f^{-\Delta_{\mathcal{O}}} \lambda_{\mathcal{O}} \ll 1$$

  - The deforming operator is nearly marginal at the breaking scale $\epsilon \ll 1$

Dilaton Mass

- Make $\lambda_{\mathcal{O}}$ a spurion to trace conformal symmetry violation

$$\mathcal{L}_{\rm CFT} + \lambda_{\mathcal{O}}\mathcal{O} \qquad\qquad \lambda_{\mathcal{O}} \to e^{(4-\Delta_{\mathcal{O}})\omega}\lambda_{\mathcal{O}}$$

- To leading order in $\lambda_{\mathcal{O}}$

$$V(\chi) = \kappa_0\chi^4 + \kappa_1\lambda_{\mathcal{O}}\chi^{\Delta_{\mathcal{O}}}$$

- Leads to dilaton mass

Symmetry Breaking Parameters

$$m_\sigma^2 = 4f^2\kappa_0(4-\Delta_{\mathcal{O}}) \sim (4\pi f)^2\widehat{\lambda}_{\mathcal{O}}(f)\epsilon$$

A More Correct Analysis

- Because the CFT is deformed, $\widehat{\lambda}_{\mathcal{O}}$ runs

$$\frac{d\ln\widehat{\lambda}_{\mathcal{O}}}{d\ln\mu} = -g(\widehat{\lambda}_{\mathcal{O}}) = -\sum_{n=0}^{\infty} c_n \widehat{\lambda}_{\mathcal{O}}^n$$

- With $c_0 = -\epsilon$ and all other $c_i \sim 1$
- Including this effect we find

$$m_\sigma^2 \sim (4\pi f)^2 \underset{\uparrow}{\widehat{\lambda}_{\mathcal{O}}(f)}\, \underset{\uparrow}{g}(\widehat{\lambda}_{\mathcal{O}}(f))$$

Symmetry Breaking
Parameters

Light Dilaton Not Generic

- What changes from $\widehat{\lambda}_{\mathcal{O}}\epsilon \to \widehat{\lambda}_{\mathcal{O}} g(\widehat{\lambda}_{\mathcal{O}})$?
- Typically the CFT breaks when $\widehat{\lambda}_{\mathcal{O}} \sim 1$
- In this case $g(\widehat{\lambda}_{\mathcal{O}}) \sim \widehat{\lambda}_{\mathcal{O}} \gg \epsilon$ so the mass is of the order of the breaking scale
- When is the dilaton light?
  - Naturally Light: Fixed Lines, Conformal Window
  - Tuning to break before $\widehat{\lambda}_{\mathcal{O}} \sim 1$
    - Tuning is linear, mild

Corrected Couplings

- Consider the gauge boson mass term

$$\left(\frac{\chi}{f}\right)^2 \left[1 + \alpha_W \widehat{\lambda}_{\mathcal{O}} \chi^{\Delta_{\mathcal{O}}-4}\right] \frac{\widehat{m}_W^2}{\widehat{g}^2} W_\mu W^\mu$$

- Leads to correction to the boson mass

$$\frac{m_W^2}{g^2} = \left[1 + \alpha_W \widehat{\lambda}_{\mathcal{O}}(f) f^{\Delta_{\mathcal{O}}-4}\right] \frac{\widehat{m}_W^2}{\widehat{g}^2}$$

Corrected Couplings

- This leads to

Symmetry Breaking Parameters

$$\frac{\sigma}{f}\left[2 + c_W \epsilon \widehat{\lambda}_{\mathcal{O}}(f)\right] \frac{m_W^2}{g^2} W_\mu^+ W^{\mu -}$$

Corrected Mass

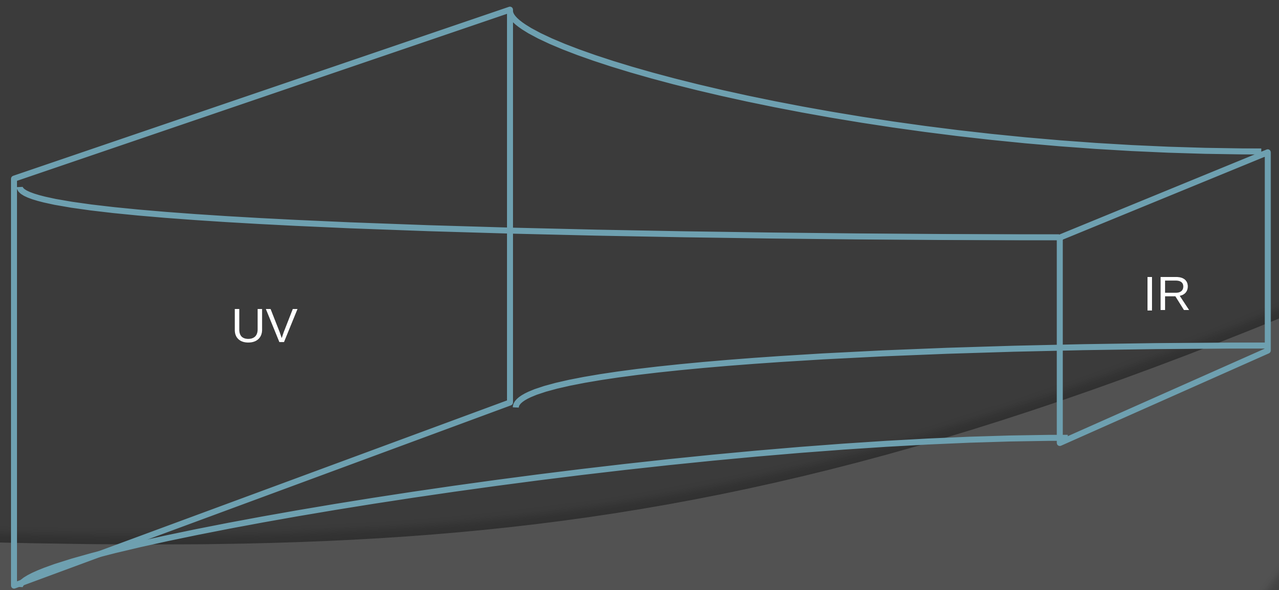
- Exact form from dilaton mass!
- Corrections goes like $\dfrac{m_\sigma^2}{\Lambda_{\mathrm{IR}}^2}$

The Dilaton Story

- Realistic models predict a massive dilaton
- Theories with a light dilaton are somewhat special, but phenomenologically interesting
- Couplings are dictated by conformal symmetry with corrections of order $\frac{m_\sigma^2}{\Lambda_{\mathrm{IR}}^2}$

Randall-Sundrum Models

- One additional spatial dimension which is highly curved
- With SM fields in the bulk, addresses the gauge hierarchy problem and fermion mass hierarchy puzzle



RS Models

- New states:
  - Kaluza-Klein modes
  - The Radion
- Related to a strongly coupled CFT in four dimensions by AdS/CFT

RS Geometry

- RS Gravity Action

$$S = \int d^4x d\theta \left[\sqrt{G} \left(-2M_5^3 \mathcal{R}_5 - \Lambda_b \right) \right.$$

$$\left. - \sqrt{-G_{\mathrm{UV}}}\,\delta(\theta) T_{\mathrm{UV}} - \sqrt{-G_{\mathrm{IR}}}\,\delta(\theta - \pi) T_{\mathrm{IR}} \right]$$

- With metric

$$ds^2 = e^{-2kr_c|\theta|} \eta_{\mu\nu} dx^\mu dx^\nu - r_c^2 d\theta^2 \qquad -\pi \leq \theta \leq \pi$$

- We parameterize the radion by letting

$$r_c \to r(x)$$

Radion Potential

- Integrate over the extra dimension to find

$$\int d^4x\sqrt{-g}\left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)$$

- With radion field

$$\varphi(x) = Fe^{-k\pi r(x)} \quad F = \sqrt{\frac{24M_5^3}{k}}$$

- And potential (it's quartic! Think duality)

$$V_{\mathrm{GR}}(\varphi) = \frac{\varphi^4}{F^4}\left(T_{\mathrm{IR}} - \frac{\Lambda_b}{k}\right) \Leftrightarrow \kappa_0\chi^4$$

Radion Phenomenology

- Couplings dictated by general covariance
  - Look Higgs-ish
- Tuning issue in the potential
  - If $kT_{\mathrm{IR}} > \Lambda_b$ then $\langle r \rangle \equiv r_c \to \infty$
  - If $kT_{\mathrm{IR}} < \Lambda_b$ then $r_c \to 0$
  - If $kT_{\mathrm{IR}} = \Lambda_b$ then r_c is unconstrained. Tuned.

$$V_{\mathrm{GR}}(\varphi) = \frac{\varphi^4}{F^4}\left(T_{\mathrm{IR}} - \frac{\Lambda_b}{k}\right)$$

Goldberger-Wise Mechanism

- The radius r_c can be stabilized by a bulk scalar

$$S = \int d^4x d\theta \left[\sqrt{G} \left(\frac{1}{2} G^{AB} \partial_A \Phi \partial_B \Phi - V_b(\Phi) \right) \right.$$

$$\left. - \sqrt{-G_{\mathrm{UV}}}\delta(\theta) V_{\mathrm{UV}}(\Phi) - \sqrt{-G_{\mathrm{IR}}}\delta(\theta - \pi) V_{\mathrm{IR}}(\Phi) \right]$$

- In general Φ depends on $r(x)$ and contributes to the radion potential and leads to stabilization

Equation for Φ

- Φ satisfies

$$\partial_\theta^2 \Phi - 4kr_c \partial_\theta \Phi - r_c^2 \frac{dV_b}{d\Phi} = 0$$

- In general

$$V_b(\Phi) = \frac{1}{2} m^2 \Phi^2 + \frac{1}{3!} \eta \Phi^3 + \ldots$$

- Including any but the mass term leads to a nonlinear ODE even neglecting back reaction

RS Holography

CFT		RS
UV Cutoff	$\Leftrightarrow$	UV Brane
Symmetry Breaking Scale	$\Leftrightarrow$	IR Brane
RG Scale, μ	$\Leftrightarrow$	Warped Dimension, θ
Dilaton, σ	$\Leftrightarrow$	Radion, φ
Explicit Symmetry Breaking, $\lambda_{\mathcal{O}}$	$\Leftrightarrow$	GW Scalar, Φ

Φ Holography

- Equation governing $\widehat{\lambda}_{\mathcal{O}}$ is first order

$$\frac{d\ln \widehat{\lambda}_{\mathcal{O}}}{d\ln \mu} = -g(\widehat{\lambda}_{\mathcal{O}})$$

- Equation governing Φ is second order

$$\partial_\theta^2 \Phi - 4kr_c \partial_\theta \Phi - r_c^2 \frac{dV_b}{d\Phi} = 0$$

- How can $\lambda_{\mathcal{O}}(\mu)$ and $\Phi(\theta)$ be dual to each other?

Φ Holography

$$\cancel{\partial_\theta^2 \Phi} - 4kr_c \partial_\theta \Phi - r_c^2 \frac{dV_b}{d\Phi} = 0$$

- For a large hierarchy $kr_c \gg 1$ and so

$$\frac{d\Phi}{d\theta} = -\frac{r_c}{4k}\frac{dV_b}{d\Phi} \quad \left(0 \leq \theta \leq \pi - \frac{1}{4kr_c}\right)$$

- Or

$$\frac{d\ln\Phi}{d(kr_c\theta)} = -\frac{m^2}{4k^2} - \frac{\eta}{8\sqrt{k}}\frac{\Phi}{k^{3/2}} - \ldots$$

Φ Holography

- Value of $\widehat{\lambda}(\mu)$ dual to $k^{-3/2}\Phi(\theta)$
- So $$\frac{d\ln\widehat{\lambda}}{d\ln\mu} = \epsilon - c_1\widehat{\lambda} - \ldots$$
- is dual to $$\frac{d\ln\Phi}{d(kr_c\theta)} = -\frac{m^2}{4k^2} - \frac{\eta}{8\sqrt{k}}\frac{\Phi}{k^{3/2}} - \ldots$$
- Mass of Φ dual to scaling dimension of $\mathcal{O}$

$$\Delta_{\mathcal{O}} = 4 - \epsilon = 4 + \frac{m^2}{4k^2}$$

The Small Parameters

$$\widehat{\lambda}_{\mathcal{O}} \to k^{-3/2}\Phi \qquad \widehat{\lambda}_{\mathcal{O}} g(\widehat{\lambda}_{\mathcal{O}}) \Leftrightarrow k^{-3/2}\frac{d\Phi}{d(kr_c\theta)}$$

$$g(\widehat{\lambda}_{\mathcal{O}}) \to \frac{d\ln\Phi}{d(kr_c\theta)}$$

- Consider the constant Φ limit
  - Parameters rescaled
  - No stabilization
- Radion mass depends on $\dfrac{d\Phi}{d(kr_c\theta)}$
- In theories of interest $\dfrac{d\Phi}{d(kr_c\theta)} \ll 1$ until near the breaking scale

Radion Mass

- Dual to dilaton, mass is generically of order the KK scale
- Natural light mass if Φ a pNGB (dual to a quasi-fixed line)
- Other theories with a light Radion employ mild tuning
- In all light mass cases, Φ is a slowly varying function:

$$\frac{d\Phi}{d(kr_c\theta)} \ll 1$$

Radion Couplings after Stabilization

- Will show corrections to couplings to bulk SM fields
- Demonstrate how holography organizes the results
  - Correction that do not affect the form of the dilaton couplings
  - Corrections to the form
- Corrections to the form are of order $\dfrac{m_\varphi^2}{m_{\mathrm{KK}}^2}$

Massive Gauge Bosons

- Mass term

$$S = \int d^4x d\theta \delta(\theta - \pi)\sqrt{-G_{\mathrm{IR}}} G_{\mathrm{IR}}^{\mu\nu}(\mathcal{D}H)(\mathcal{D}H)^\dagger$$

$$\Rightarrow \int d^4x e^{-2kr(x)\pi} W_\mu W^\mu \langle H\rangle^2$$

- Let $r(x) \to r_c + \delta r(x)$ or $\varphi(x) \to f + \widetilde{\varphi}(x)$

  with $-k\pi\delta r = \dfrac{\widetilde{\varphi}}{f}$

Massive Gauge Bosons

- Then

$$S = \int d^4x e^{-2kr_c\pi} \langle H \rangle^2 W_\mu W^\mu \left(1 + 2\frac{\widetilde{\varphi}}{f}\right)$$

- So the coupling is

$$2\frac{m_W^2}{g_4^2}\frac{\widetilde{\varphi}}{f}W_\mu W^\mu$$

Basis Choice

- Similar to the Higgs

Stabilized Massive Gauge Boson

- Now,

$$\int d^4 x e^{-2kr(x)\pi} \langle H \rangle^2 W_\mu W^\mu \left(1 + \frac{\beta_W}{k^{3/2}} \Phi(\pi)\right)$$

- Note that the mass is altered, same as CFT
- As $r \to r_c + \delta r$, we find

$$\Phi(\theta k r) \to \Phi_c(\theta k r_c) + \delta r\, \theta k \Phi_c'$$

where

$$\Phi_c' \equiv \frac{d\Phi_c}{d(k r_c \theta)}$$

Stabilized Massive Gauge Boson

- Finally,

$$\int d^4x \frac{m_W^2}{g_4^2} W_\mu W^\mu \left[1 + \frac{\widetilde{\varphi}}{f}\left(2 - \frac{\beta_W \Phi_c'(\pi)}{k^{3/2} + \beta_W \Phi_c(\pi)}\right)\right]$$

- Note the altered mass
- From duality

$$g(\widehat{\lambda}_{\mathcal{O}})\widehat{\lambda}_{\mathcal{O}} \Leftrightarrow k^{-3/2}\Phi_c'$$

- Radion coupling correction goes like $\dfrac{m_\varphi^2}{m_{\mathrm{KK}}^2}$

Gauge Boson Kinetic Term

- Bulk gauge bosons are dual 4D gauge fields that weakly gauge global symmetries of the CFT
- The kinetic term is classically conformal, but the gauge coupling runs above and below the breaking scale

Flavor/Planck Scale

$\big\downarrow\ b_>$

CFT Breaking Scale

$\big\downarrow\ b_<$

$$\frac{d}{d\ln\mu}\frac{1}{g^2_{\mathrm{UV,IR}}} = \frac{b_{>,<}}{8\pi^2} \qquad \frac{b_< - b_>}{32\pi^2}\frac{\sigma}{f}F_{\mu\nu}F^{\mu\nu}$$

Gauge Boson Kinetic Term

- Before stabilization

$$-\int d^4x d\theta \frac{F^2}{4}\left[\delta(\theta)\frac{\sqrt{-G_{\rm UV}}}{g_{\rm UV}^2}+\frac{\sqrt{G}}{g_5^2}+\delta(\theta-\pi)\frac{\sqrt{-G_{\rm IR}}}{g_{\rm IR}^2}\right]$$

- In KK decomposition the zero mode has a flat profile
- Integrate over θ to find

$$\frac{1}{g_4^2}=\frac{1}{g_{\rm UV}^2}+\frac{2\pi r_c}{g_5^2}+\frac{1}{g_{\rm IR}^2}$$

Gauge Boson Kinetic Term

- Integrate over θ and let $r \rightarrow r_c + \delta r$

$$-\int d^4x d\theta \frac{F^2}{4} \left[\delta(\theta) \frac{\sqrt{-G_{\mathrm{UV}}}}{g_{\mathrm{UV}}^2} + \frac{\sqrt{G}}{g_5^2} + \delta(\theta - \pi) \frac{\sqrt{-G_{\mathrm{IR}}}}{g_{\mathrm{IR}}^2} \right]$$

- Yields coupling $\dfrac{1}{2kg_5^2} \dfrac{\widetilde{\varphi}}{f} F^2$

Loop Effects

- In the effective theory $-\frac{1}{4g^2(\mu)}F^2$ with

$$g_4^2 = g^2(\Lambda_{\text{IR}} = ke^{-kr\pi})$$

- From the RGE

$$\frac{1}{g^2(\mu)} = \frac{1}{g_4^2} - \frac{b_<}{8\pi^2}\ln\frac{ke^{-kr\pi}}{\mu}$$

$r + \delta r$

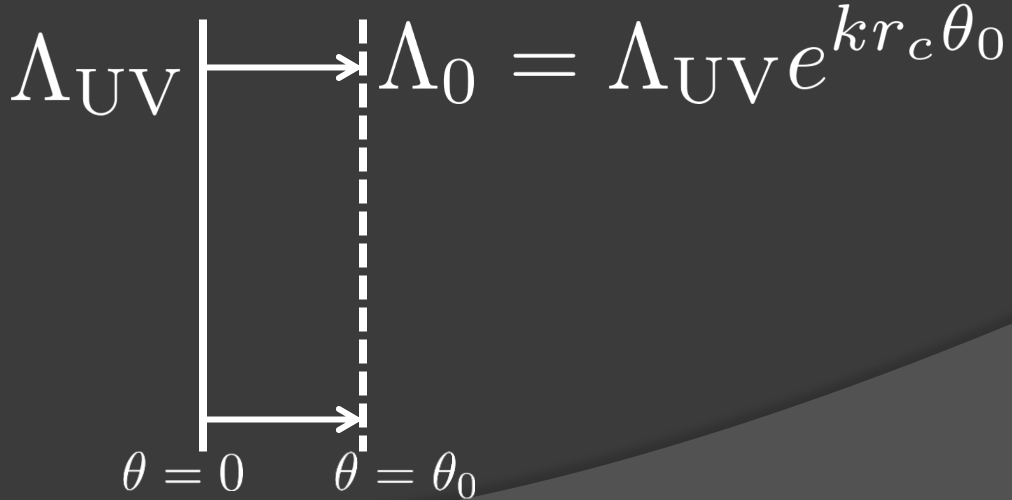
- Leads to dilaton coupling

$$\frac{b_<}{32\pi^2}\frac{\widetilde{\varphi}}{f}F^2$$

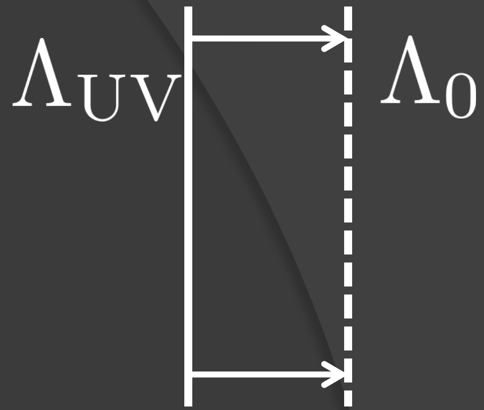
Holographic Guide

- To one loop $\left(\frac{1}{2kg_5^2} + \frac{b_<}{32\pi^2}\right)\frac{\widetilde{\varphi}}{f}F^2$

- To relate to the CFT parameter $b_>$ move the UV brane



Holographic Guide



- Integrating the action from 0 to θ_0 we find

$$\frac{1}{g^2(\theta_0)_{\mathrm{UV}}} = \frac{1}{g_{\mathrm{UV}}^2} + \frac{2\theta_0 r_c}{g_5^2}$$

- So

$$\frac{b_>}{8\pi^2} = \frac{d}{d\ln\Lambda_0}\frac{1}{g^2(\Lambda_0)} = -\frac{1}{kr_c}\frac{d}{d\theta_0}\frac{1}{g_{\mathrm{UV}}^2(\theta_0)} = -\frac{2}{kg_5^2}$$

$$\left(\frac{1}{2kg_5^2} + \frac{b_<}{32\pi^2}\right)\frac{\widetilde{\varphi}}{f}F^2 = \frac{b_< - b_>}{32\pi^2}\frac{\widetilde{\varphi}}{f}F^2$$

Stabilized Coupling

- Add GW couplings

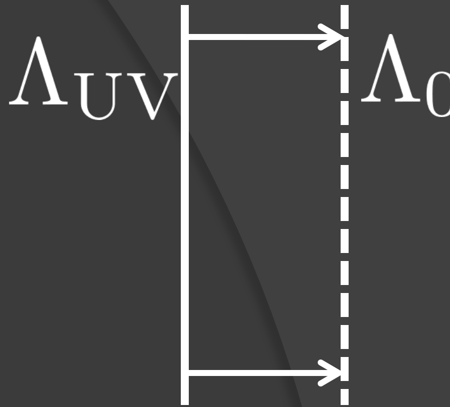
$$\frac{F^2}{4}\left[\delta(\theta)\frac{\sqrt{-G_{\rm UV}}}{g_{\rm UV}^2}\beta_{\rm UV}+\frac{\sqrt{G}}{g_5^2}\beta_5+\delta(\theta-\pi)\frac{\sqrt{-G_{\rm IR}}}{g_{\rm IR}^2}\beta_{\rm IR}\right]\frac{\Phi}{k^{3/2}}$$

- To 1-loop, recalling $\Phi \to \Phi_c + \delta r\,\theta k \Phi_c'$

$$\left[\frac{1}{2kg_5^2}\left(1+\underbrace{\frac{\beta_5}{k^{3/2}}\Phi_c(\pi)}_{\text{Big correction!}}\right)+\frac{\beta_{\rm IR}}{4g_{\rm IR}^2k^{3/2}}\underbrace{\Phi_c'(\pi)}_{\frac{m_\varphi^2}{m_{\rm KK}^2}}+\frac{b_<}{32\pi^2}\right]\frac{\varphi}{f}F^2$$

- Big correction!
  What's going on?

$$\frac{m_\varphi^2}{m_{\rm KK}^2}$$



Holographic Analysis

- Could this term be part of $b_>$?
- Move the UV brane to θ_0

$$\frac{1}{g_{\mathrm{UV}}^2(\Lambda_0)} = \frac{1}{g_{\mathrm{UV}}^2} + \frac{2r_c}{g_5^2}\int_0^{\theta_0} d\theta \left(1 + \frac{\beta_5}{k^{3/2}}\Phi_c(\theta)\right)$$

- Use RGE

$$\frac{b_>}{8\pi^2} = \frac{d}{d\ln\Lambda_0}\frac{1}{g^2(\Lambda_0)} = -\frac{1}{kr_c}\frac{d}{d\theta_0}\frac{1}{g_{\mathrm{UV}}^2(\theta_0)}$$

Holographic Analysis

- Pushing the scale all the way to $\theta_0 = \pi$

  leads to $$\frac{b_>}{8\pi^2} = -\frac{2}{kg_5^2}\left(1 + \frac{\beta_5}{k^{3/2}}\Phi_c(\pi)\right)$$

$$\left[\frac{1}{2kg_5^2}\left(1 + \frac{\beta_5}{k^{3/2}}\Phi_c(\pi)\right) + \frac{\beta_{\mathrm{IR}}}{4g_{\mathrm{IR}}^2 k^{3/2}}\Phi_c'(\pi) + \frac{b_<}{32\pi^2}\right]\frac{\varphi}{f}F^2$$

- Becomes $$\left[\frac{b_< - b_>}{32\pi^2} + \frac{\beta_{\mathrm{UV}}}{4g_{\mathrm{UV}}^2}\frac{\Phi_c'(\pi)}{k^{3/2}}\right]\frac{\varphi}{f}F^2$$

- Only corrections to the <u>form</u> are $$\frac{m_\varphi^2}{m_{\mathrm{KK}}^2}$$

Bulk Fermions

- Analysis proceeds as in gauge boson case
- As the profiles are not flat the analysis is more complicated
- Corrections to the scaling dimension of CFT operators by stabilization
- Corrections to the dilaton form by $\dfrac{m_\varphi^2}{m_{\mathrm{KK}}^2}$

Conclusions

- Composite Higgs theories with CFT completion may posses a light dilaton
- Such theories are a result of *near* conformality
- This near conformality is small parameter
- Changes to radion couplings can be calculated and agree with dilaton analysis
- Corrections to massless dilaton form go like $\dfrac{m_\varphi^2}{m_{\mathrm{KK}}^2}$